device, and also reduce its efficiency because of the additional energy consumption associated with the agitation mechanism itself..

Another disadvantage of prior art devices is that the spaced grids of refrigerant piping cannot easily be changed. Switching pipes may be necessary for repair but also for changing the pipe material to suit different refrigerants. For example, copper is unsuitable for use with ammonia.

It is an object of the present invention to overcome or ameliorate one or more of the disadvantages of the prior art, or at least to provide a useful alternative.

SUMMARY OF THE INVENTION AND OBJECT

According to a first aspect of the invention, there is provided a thermal storage device including:

a generally cylindrical tank including outer sidewalls adapted to contain a first fluid;

a heat exchange fluid inlet to said tank;

a heat exchange fluid outlet from said tank;

a refrigeration unit;

at least one hollow refrigeration evaporator coil in fluid communication with said refrigeration unit by means of refrigerant feed and extraction pipes, said coil being helically disposed within said tank for freezing the first fluid adjacent the coil, such that in use the frozen fluid and the sidewalls together define a substantially helical path to direct the flow of a heat exchange fluid from said inlet to said outlet.

Preferably, the device further includes a generally cylindrical column fixed with respect to the tank and extending coaxially through an interior region of the tank. More preferably, the column supports the coil and defines an inner sidewall of the tank. Even more preferably, the column is removably mounted within tank.

Preferably, the device includes valve means disposed selectively to introduce relatively hot fluid into the coil to rapidly heat an outer surface thereof, so as to crack and create fissures in the frozen fluid and thereby increase the rate of freezing of the first fluid. More preferably, the valve means include a reversing valve operable on the refrigerant feed pipe.

Figure 3 is a sectional side elevation of another embodiment of the refrigeration device with a slightly changed evaporator coil disposition to ease manufacture;

Figure 4 is a schematic layout of a refrigeration circuit incorporating the refrigeration device, the circuit being configured to chill water to ice and recover waste heat; and

Figure 5 is a schematic layout of the device showing various control components.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Figures 1 to 3 of the drawings, the refrigeration device 10 includes a right circular cylindrical tank 11 having a central cylindrical column 12 defining an annular operative chamber 13 bounded by outer and inner sidewalls 14 and 15 respectively.

The tank is positioned vertically about an axis 16 and includes a heat exchange fluid inlet 17 adjacent the top of the tank and a corresponding outlet 18 at the base of the tank. In this embodiment, the heat exchange fluid is water.

The central column 12 supports a pair of refrigeration coils 19 and 20, each concentrically disposed within the tank in the form of a regular helix. The helices are of identical pitch in terms of revolutions per unit length, but of differing radii and are axially positioned such that in a section taken on a plane including the tank axis, at any given point the adjacent sections of the respective coils are always substantially disposed on a common radial line, as shown in Figure 3.

The coils 19 and 20 are each in fluid communication with a refrigeration unit 60 by means of a respective refrigerant feed pipe 61 and an extraction pipe 62.

In this embodiment, the coils are horizontally spaced in section as illustrated. In alternative embodiments where only a single refrigerant coil is used or where two or more coils are provided but are not horizontally aligned, the invention will operate, but may do so less efficiently.

Agitation means in the form of an axially extending perforate tube 63 is mounted within the tank 11. The tube includes an array of axially spaced nozzles 64 for injecting material into the water to increase its flow rate and turbulence. In this embodiment, the nozzles take the form of apertures in the tube. The increased

agitation has the effect of reducing the effective freezing point of the water, thereby allowing its temperature to drop to below 0°C without forming ice. The injection may be powered from the supply water or using a separate pump.

A typical refrigeration circuit including a refrigeration device as described above is illustrated in Figure 4. The circuit includes a compressor 41, suction accumulation vessel 43, oil trap 42, condenser 44, thermostatic expansion valve 46 and the evaporator coils 45 which are immersed in the thermal storage tank 48. The thermostatic expansion valve is typically controlled by sensing the exit temperature of the refrigerant from the evaporator tube by means of a sensor 49. The thermostatic expansion valve controls the ice temperature, which is typically set at -10°C.

A typical control system for the device is illustrated in Figure 5 and includes several features in common with the refrigeration circuit, with corresponding reference numerals indicating like features.

The control system includes valve means 65 disposed selectively to introduce relatively hot fluid into the coil to rapidly heat an outer surface thereof, so as to crack and create fissures in said frozen fluid and thereby increase the rate of freezing of the first fluid. The valve means including a reversing valve 47 operable on the refrigerant feed pipe.

An electronic expansion valve 46 is operable on the refrigerant feed pipe for metering the evaporation of refrigerant gas within the evaporation coil. A pair of sensors 66 and 67 are positioned to detect propagation of an interface between a frozen phase and surrounding liquid phase of the first fluid between respective predetermined maximum and minimum positions in response to progressive freezing of the first fluid.

The control system further includes a temperature sensor 68 on the outlet and a temperature sensor 69 on the inlet. The outlet sensor 68 ensures that water is supplied at the design temperature. The inlet sensor 69 detects the return temperature of the heat exchange fluid entering the tank. A timer 70 is included to activate the refrigeration unit in off-peak periods. A manual override mechanism (not shown) is also provided to permit activation of the refrigeration unit outside of off-peak periods.

An inlet pressure sensor 71 detects pressure in the inlet and an outlet pressure sensor 72 detects pressure in the outlet. The inlet and outlet pressure sensors, among

other functions, detect a build-up of pressure resulting from a blockage in the system. High and low pressure sensors 73 and 74 ensure that the refrigeration compressor operates within safe working limits. A condenser fan controller 75 controls condenser fans (not shown) and optimises condensation.

A solenoid valve 76 is positioned to close the refrigeration circuit and also to allow multiple thermal storage devices to be connected to a single refrigeration unit. A pump 77 is provided and is responsive to a speed controller 78. The speed controller adjusts the pump speed based on the temperature sensed by the inlet temperature sensor 69. Where this temperature is higher than the optimal level, the pump speed in increased accordingly.

Electronic control means 79, including a microprocessor 80, control the operation of the device in response to adjustable set-points and predetermined system parameters including outputs from the various sensors described above.

The controller is adapted for remote monitoring, supervision and adjustment of various system parameters. The remote monitoring may be achieved through a modem and phone line, the Internet, or wireless devices such as GSM phones.

It will be appreciated that some or all of the control devices may be used, depending on the particular application. For example, in more cost sensitive market segments, or where maximum efficiency is of secondary importance, the condenser fan controller 75 and electronic expansion valve 46 may be omitted.

In use, the tank is filled almost completely with water and the refrigeration coils are operated as an evaporator to freeze the adjacent water. As this freezing process continues, the growing ice helices bridge the gap between the refrigeration coils and coalesce into a single ice helix.

The coils are positioned with respect to the tank sidewalls such that the freezing process can be permitted to continue until the ice helix touches or almost touches one or both of the inner and outer sidewalls. This stage is determined by the sensor 66, which detects the maximum extent of ice growth. The sensor may, for example, detect this stage through changes in resistance between the liquid and solid phases.

The over freezing of the ice mass may also be detected by the placement of thermocouples in areas where the ice mass is to stop forming. Once the temperature

of these thermocouples falls below freezing point, the ice mass has progressed to its design limit and the refrigeration plant is shut down.

It has been found that if the thermocouples are repetitively frozen in the ice mass, they may become damaged and unreliable. This defect has been ameliorated by placing the thermocouples 84 in a metal tube 85 which is partially filled with a low freezing point liquid such as ethylene glycol to effect heat transfer to the thermocouples, thus enabling the thermocouples to sense temperatures below the freezing point of water without being subjected to the stress of being embedded in a frozen fluid.

The second sensor 67, which detects minimum extent of ice growth, ensures that a sufficient amount of ice is present to provide output water at the design temperature.

During the freezing of the ice helix, the ice formed around the helical evaporator coils increases in thickness and forms and insulation barrier to the further transfer of heat from the water in the tank to the evaporator coils thus slowing down the rate of ice growth. It has been found that if the evaporator coils are suddenly heated, the ice growth on the coils cracks, creating water paths through fissures in the ice to the evaporator coils and thus improving heat transfer and allowing more rapid growth of the ice layer around the coils.

With sufficient heat, it has also been found that discrete blocks of cracked ice can be broken away from the ice helices entirely so as to float freely in the tank, thereby further increasing the rate of ice formation on the coils, as well as increasing the total effective surface area of ice available for heat transfer.

Referring to Figure 4, the sudden introduction of heat into the evaporator coils is accomplished by means of hot gas injection from the refrigeration compressor 41. The injection is controlled by opening the reversing valve 47 on the refrigerant feed pipe 61 for a short period of time, thereby very rapidly raising the temperatures of the coils.

The hot gas injection may be controlled on a time basis throughout the freezing cycle or alternatively by means of sensors that detect the rate of ice build up or heat removal from the chilled water. In one embodiment, the sensor is a monitor on the refrigeration circuit that measures the rate of heat rejection at the condenser.

The heat rejected at the condenser may be recovered in order to heat water for other uses within the establishment where the thermal storage device is installed. This is accomplished by using the heat exchanger 51 as a condenser for the refrigeration unit. The water to be heated enters the heat exchanger through the inlet 52 and leaves through the outlet 53.

The flexibility of the refrigeration circuit may be improved by the addition of three way valves 50 to provide for use of a regular air cooled condenser 44 in the form of a cooling tower. Alternatively, the hot water heat exchanger may be used as a condenser. This may be particularly advantageous where the temperature of the water being heated for other uses rises to a level at which the efficiency of the refrigeration unit is adversely affected.

Once the ice helix has been formed, the thermal storage tank is ready for use as a chiller by passing water through the tank from the inlet 17 to the outlet 18. The ice helix, together with the tank sidewalls, defines a substantially helical path for the water as it passes through the tank. This path is well defined and free-flowing to reduce the tendency of the water to by-pass the helix adjacent the tank sidewalls.

It is also apparent that the water is in constant heat exchange contact with the ice over a distance much greater than the length of the tank. The actual contact length is dependent on the size of the tank and the pitch of the coils. The pitch is approximately 12° in this embodiment and on that basis, a tank of 1.9 metres in length produces approximately 44 metres of helical path.

Water flow along the helix is promoted by an appropriately directed inlet 21 and outlet 18. Because of the substantially constant temperature of the ice, provided the water flow is not excessive, chilled water can be output at a substantially constant depressed temperature of around 0.5°C.

The water temperature may be further depressed to below 0°C by adding ethylene glycol to the chilled water supply to depress the freezing temperature of the chilled water below 0°C.

The tank may be formed of any suitable material such as polyethylene. The central column in the preferred embodiment is formed of polyvinylchloride piping and serves to support the refrigerant coil by means of a plurality of copper brackets 22. The tank includes a removable lid 23 to permit easy access to the helical coils, which

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:-

1. A refrigeration device including:

a generally cylindrical tank including outer sidewalls adapted to contain a first fluid;

a heat exchange fluid inlet to said tank;

a heat exchange fluid outlet from said tank;

a refrigeration unit;

at least one hollow refrigeration evaporator coil in fluid communication with said refrigeration unit by means of refrigerant feed and extraction pipes, said coil being helically disposed within said tank for freezing the first fluid adjacent the coil, such that in use the frozen fluid and said sidewalls together define a substantially helical path to direct the flow of a heat exchange fluid from said inlet to said outlet.

2. A device according to claim 1, further including a generally cylindrical column fixed with respect to said tank and extending coaxially through an interior region of the tank.

3. A device according to claim 2, wherein said column supports said coil and defines an inner sidewall of said tank.

4. A device according to claim 3 wherein said column is removably mounted within the tank.

5. A device according to any one of the preceding claims, further including valve means disposed selectively to introduce relatively hot fluid into said coil to rapidly heat an outer surface thereof, so as to crack and create fissures in said frozen fluid and thereby increase the rate of freezing of the first fluid.

6. A device according to claim 5 wherein said hot fluid is injected at a rate and temperature sufficient to fracture discrete blocks from said frozen fluid, and thereby significantly increase an effective exposed surface area of the frozen fluid.

7. A device according to claim 5 or claim 6 wherein said valve means include a reversing valve operable on said refrigerant feed pipe.

8. A device according to any one of the preceding claims including an electronic expansion valve operable on said refrigerant feed pipe for metering the evaporation of refrigerant gas within said evaporation coil.

9. A device according to any one of the preceding claims, further including at least one sensor within said tank for detecting propagation of an interface between a frozen phase and surrounding liquid phase of the first fluid.

10. A device according to claim 9 including a pair of said sensors for detecting propagation of the interface between respective predetermined maximum and minimum positions in response to progressive freezing of the first fluid.

11. A device according to any one of the preceding claims, further including a temperature sensor on said outlet.

12. A device according to any one of the preceding claims, further including a temperature sensor on said inlet.

13. A device according to any one of the preceding claims, further including a timer adapted to activate said refrigeration unit in off-peak periods.

14. A device according to claim 13, further including a manual override mechanism disposed to permit activation of said refrigeration unit outside of off-peak periods.

15. A device according to any one of the preceding claims, further including an inlet pressure sensor for detecting pressure in said inlet.

16. A device according to any one of the preceding claims, further including an outlet pressure sensor for detecting pressure in said outlet.

17. A device according to any one of claims 9 to 16, further including electronic control means to control the operation of said device in response to predetermined system parameters.

18. A device according to claim 17 wherein said electronic control means include a microprocessor responsive to predetermined system parameters including outputs from said sensors.

19. A device according to any one of the preceding claims, further including agitation means disposed within the tank to agitate and thereby reduce the effective freezing point of said heat exchange fluid.

20. A device according to claim 19 wherein said agitation means includes at least one nozzle within said tank for injecting material into the heat exchange fluid, thereby increasing its flow rate and turbulence.

21. A device according to claim 20, wherein said agitation means include an axially extending perforate tube mounted within the tank, said tube including an array of said nozzles in the form of apertures or perforations axially spaced along its length.

22. A device according to any one of the preceding claims, wherein said coil is configured substantially in the shape of a regular helix.

23. A device according to claim 22, wherein the pitch of said coil is between 5° and around 20°.

24. A device according to claim 22 or claim 23, wherein the pitch of said coil is between 10° and around 15°.

25. A device according to any one of claims 23 to 24, wherein the pitch of said coil is approximately 12°.

26. A device according to any one of the preceding claims, including a pair of said coils disposed generally concentrically within said tank.

27. A device according to claim 25 including three or more of said coils disposed generally concentrically within said tank.

28. A device according to claim 26 or claim 27 wherein the pitch of said coils is substantially identical.

29. A device according to any one of the preceding claims wherein said tank is generally right cylindrical, and generally circular in cross-sectional profile.

30. A device according to any one of the preceding claims wherein said heat exchange fluid has a lower freezing point than said first fluid.

31. A device according to claim 30 wherein said heat exchange fluid includes ethylene glycol.

32. A method of operating a device as defined in any one of the preceding claims, including the steps of:

directing an evaporative fluid through the evaporator coil so as to reduce the temperature of an outer surface of the coil to a temperature less than or equal to the freezing point of the first fluid,

thereby causing said first fluid to freeze on the outer surface of the evaporator coil,

allowing sufficient time for an interface between solid and liquid phases of the first fluid to advance such that the frozen liquid and the sidewalls together define a substantially helical path; and

directing a heat exchange fluid to flow along said helical path such that the temperature of the heat exchange fluid progressively drops toward the temperature of the frozen first fluid.

33. A method according to claim 32 including the further step of periodically injecting a hot fluid into said coil to crack and create fissures in said frozen fluid and thereby increase the rate of freezing of the first fluid.

34. A method according to claim 33 wherein said hot fluid is injected at a rate and temperature sufficient to fracture discrete blocks from said frozen fluid, and thereby significantly increase the exposed surface area of the frozen fluid.

35. A method according to any one of claims 32 to 34 including the further step of injecting material into the heat exchange fluid to increase its flow rate or turbulence.

36. A method according to any one of claims 32 to 35 including the further step of recovering the heat extracted from said heat exchange fluid for use in other applications.

37. A method according to any one of claims 32 to 36 wherein said heat exchange fluid has a lower freezing point than said first fluid.

38. A method according to claim 36 wherein said heat exchange fluid includes ethylene glycol.

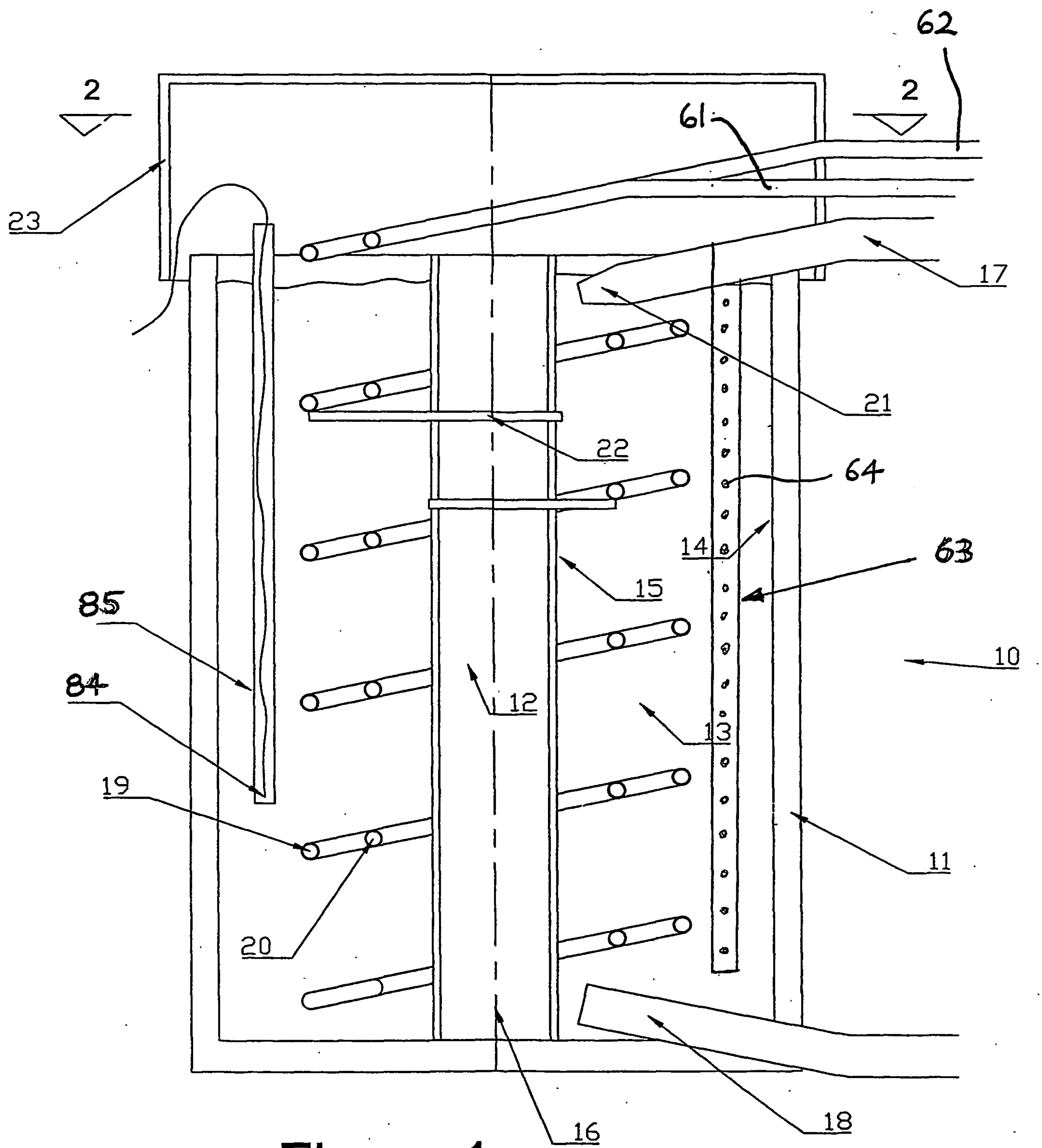

Figure 1

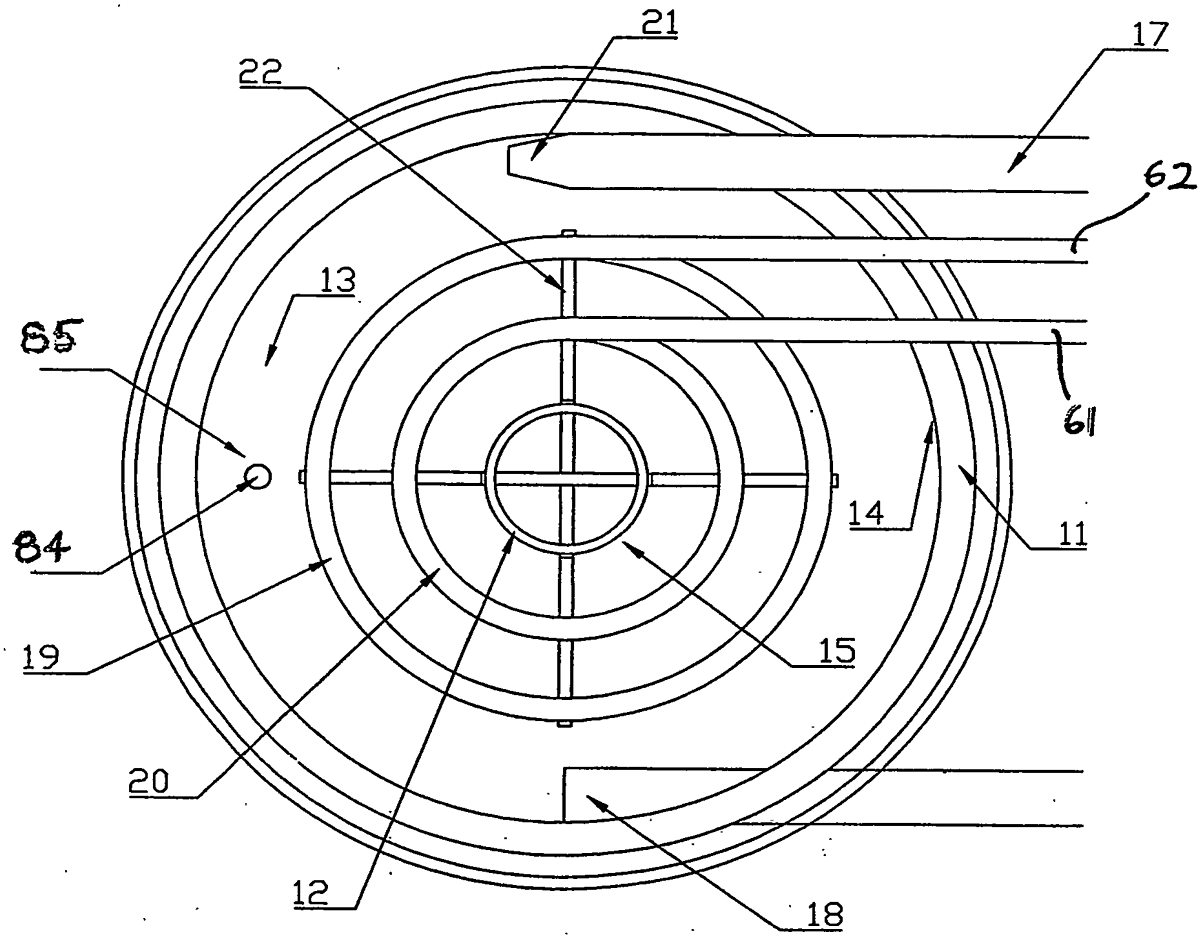

Figure 2

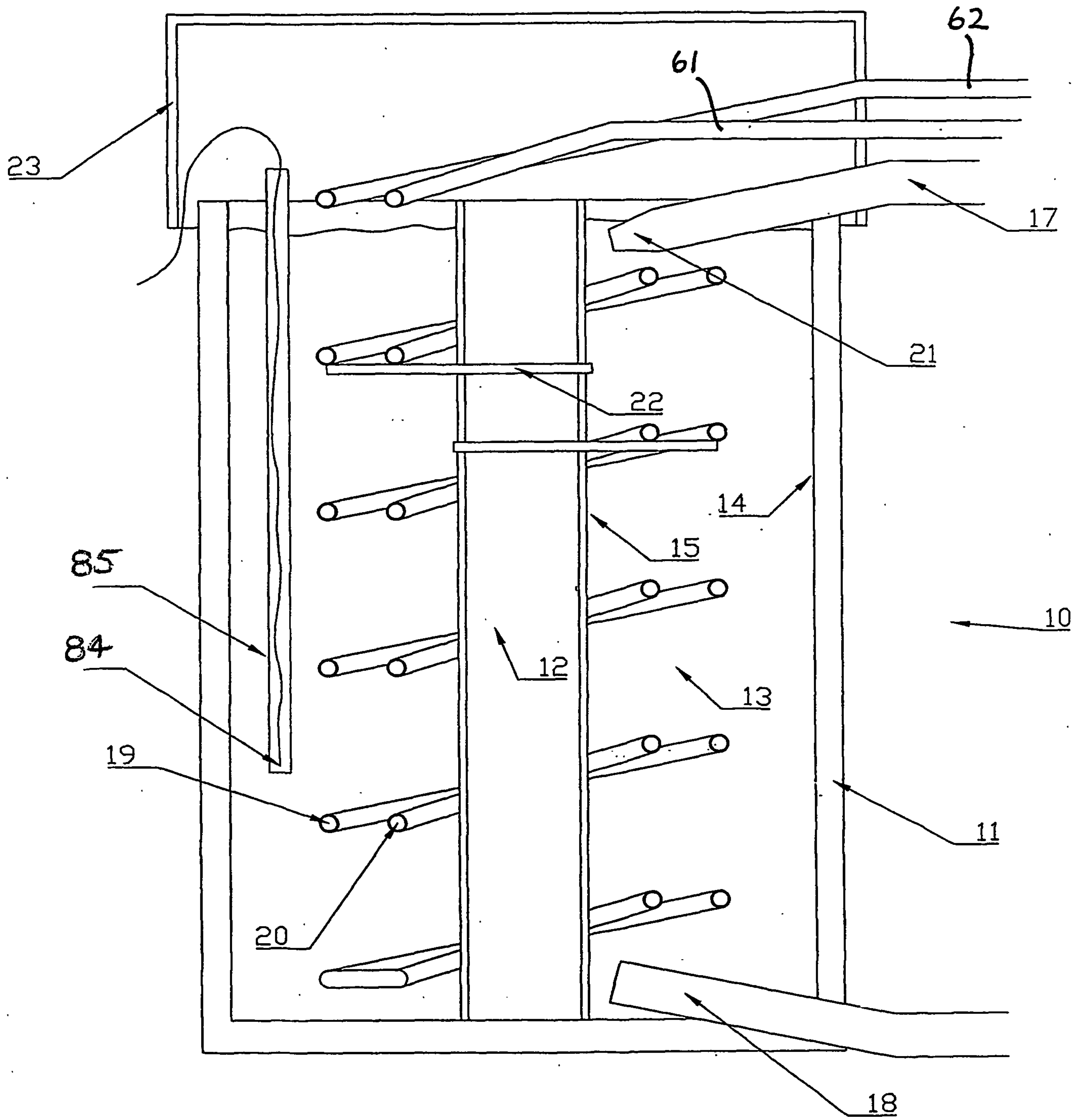

Figure 3

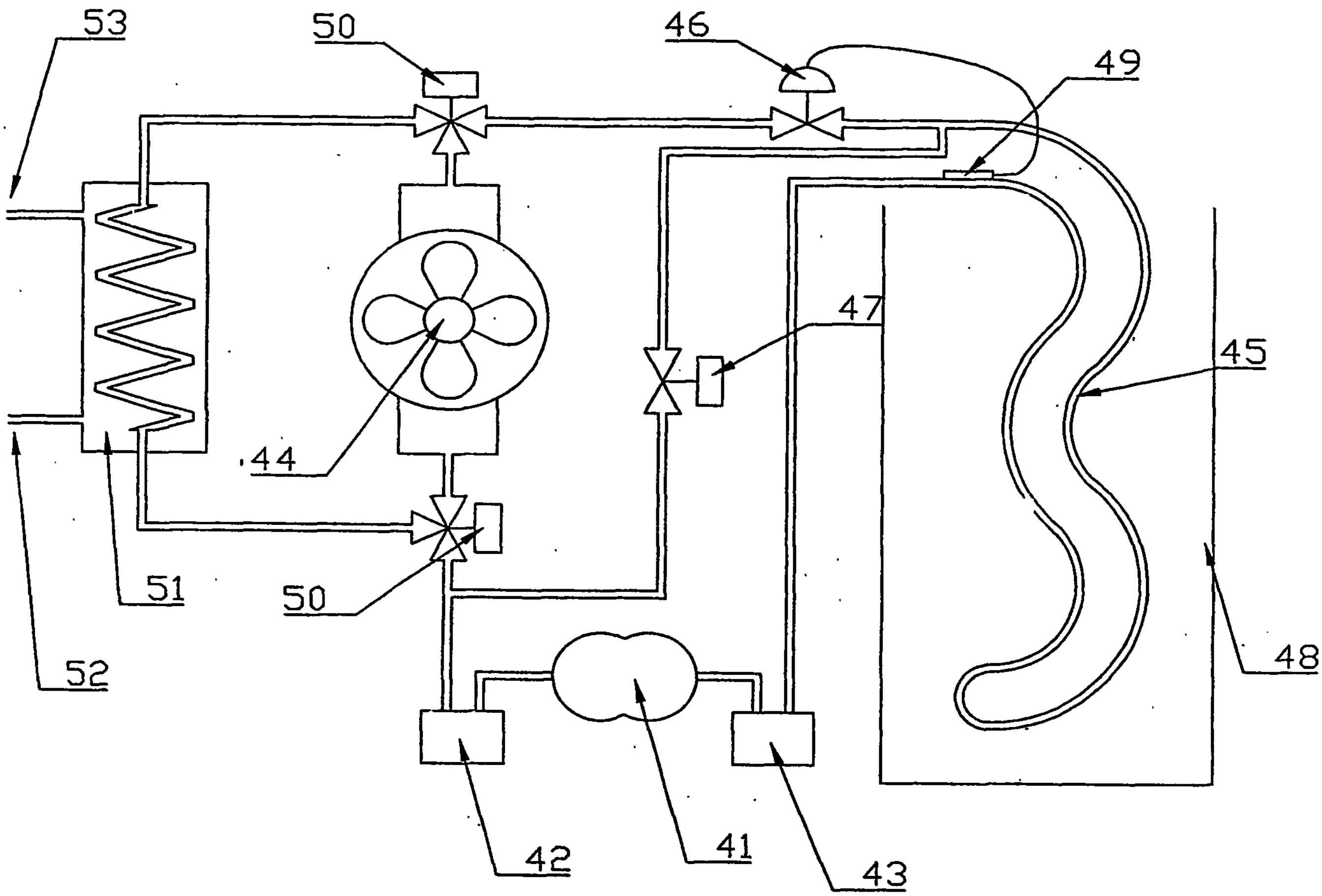

Figure 4

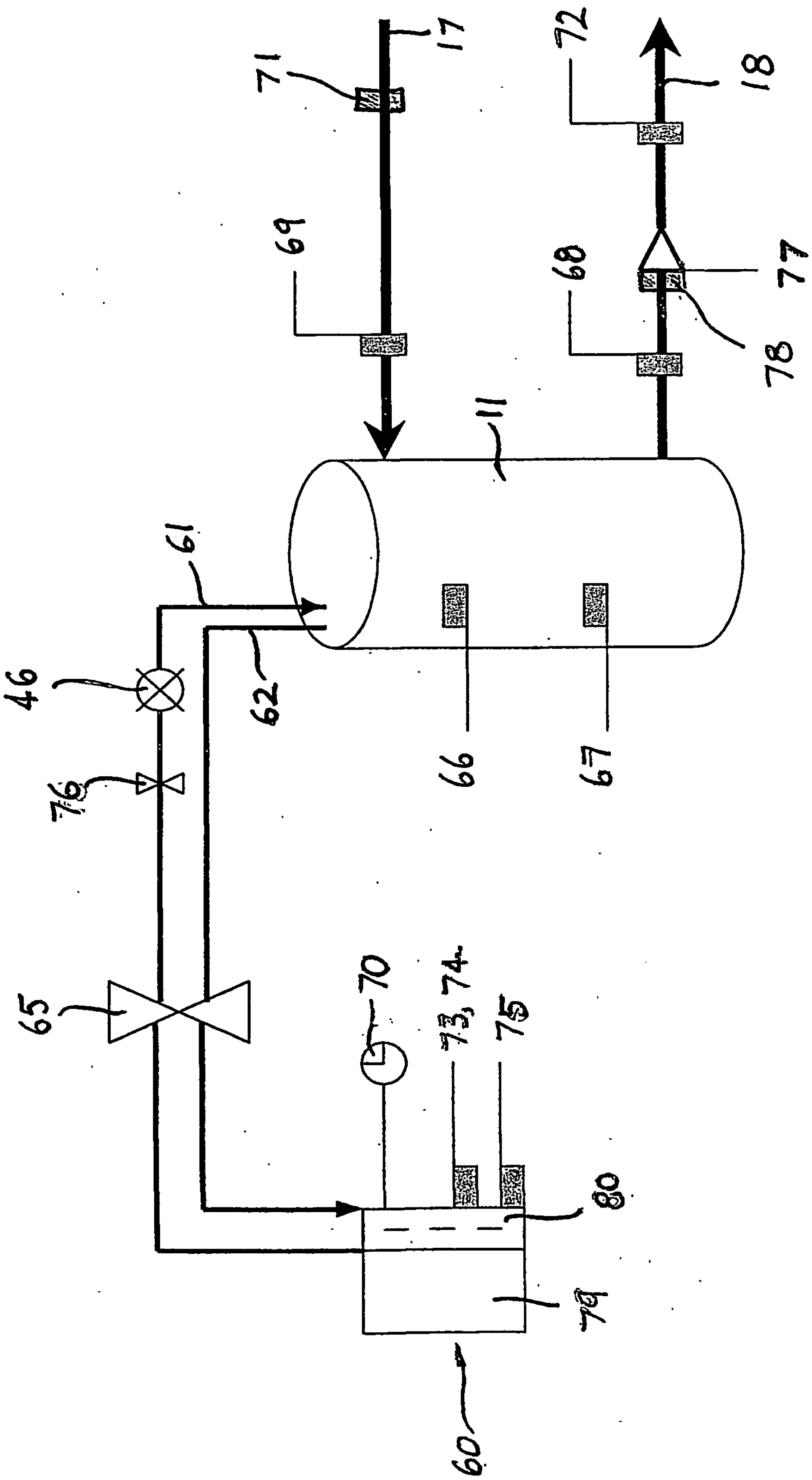

Figure 5